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A Review of the Soldier's Equipment Burden

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Land Operations Division
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ABSTRACT

The equipment load carried by the Australian Infantryman is so bulky and heavy that it presents a significant burden and impairment to his performance. This report aims to characterise this problem, to assess its impact, and provide recommendations from a range of disciplines. A survey of soldier equipment found it is set up and packed for ease of use, not ergonomic considerations. The load produces discomfort and injury, and reduces soldier and unit agility. All these findings are supported by a review of published literature. The report contains a description of the issues contributing to excessive soldier load, provides project management strategies and the change in the nature of operations, and ends with descriptions of six groups of solutions arrived at from examining the factors that make up the 'soldier equipment burden': load weight, equipment placement, and carriage duration.

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Executive Summary

The equipment load carried by Australian Infantryman is so bulky and heavy that it can present a significant impairment to his performance. Despite all the research to date no single effective solution has arisen. The aims of this three-part report are to characterise the problem, to assess its impact, and to provide recommendations from a range of disciplines to reduce the soldier's burden.

Part One of the report summarises the results of a soldier equipment survey which characterised the soldier's load by providing a real-world snapshot of the type, weight and manner in which the load was being carried, plus captured recommendations from soldiers on pack and webbing design improvements. It was observed that soldiers 'live on the outside of their pack'; meaning they pack for need first, ergonomics second. Since many high-need items are also the heaviest it may be necessary to re-consider pack design with these factors in mind. It was reported that the weights carried at the time of the survey are incongruent with the notion of manoeuvre warfare, and soldiers experience discomfort and injury from their Load Carriage Ensemble (LCE) when carrying heavy loads, so the need to reduce the equipment burden should reduce the risk of injury and improve performance.

Part Two confirms observations from part one from evidence in the open literature that the problem of soldier load carriage is a combination of reduced soldier and unit agility, increased fatigue, and high injury rates. This section examines the concept of the weight budget and addresses the question *how heavy is too heavy?* It also contains a description of the issues contributing to the excessive soldier load, including project management strategies and the change in the nature of operations. A usable definition of a *Soldier's Equipment Burden* is then outlined; being a combination of load *weight*, equipment *placement* and *duration* of carriage.

Part Three describes near-future solutions to the problem of the soldier's equipment burden, arrived at by addressing weight, placement and duration. There needs to be consideration of what is an acceptable compromise between capability loss and performance improvement. There is a need to adopt a philosophy in the acquisition cycle on reducing equipment weight by at least a few grams per item. Then, when combined (as one soldier said) 'the kilos will take care of themselves'. Reducing volume and optimising equipment location are as important as reducing weight. To that end the LCE needs to be designed to best blend operational needs with ergonomic considerations; a pack that allows soldiers to quickly access the middle contents would allow heavy items to be packed close to the soldier's natural centre of mass. The Infantryman, with such a large equipment burden, is in effect disabled compared to his normal functioning. As such the field of *assistive technologies* may provide solutions to

aide the soldier in carrying their load, or carrying part of the load for the soldier. This allows the possibility of a soldier having with them all the equipment they need when they need it without having to carry it, or at least shorten the duration of carriage. This will allow the soldier to travel further, faster, and be less fatigued (combat ready) at the end of their patrol.

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Glossary

ADF	Australian Defence Force
ALICE	All-purpose Lightweight Individual Carrying Equipment
APC	Armoured Personnel Carrier
ASLAV	Australian Light Armoured Vehicle
ARA	Australian Regular Army
ARDEC	Armament Research, Development and Engineering Center
BDE	Brigade
CBA	Combat Body Armour
COM	Centre of Mass
COTS	Commercial Off-the-Shelf
CPL	Corporal
DARPA	Defense Advanced Research Project Agency
DMO	Defence Materiel Organisation
DPDU	Disruptive Pattern Desert Uniform
DSTO	Defence Science and Technology Organisation
ET	Entrenching Tool
GFE	Government-Furnished Equipment
GLA	Grenade Launcher Attachment
HPPD	Human Protection and Performance Division
LAND 125	Australian Army's Soldier Modernisation Program
LC1	Load Condition 1: Light Order
LC2	Load Condition 2: Patrol Order
LC3	Load Condition 3: Marching Order
LCE	Load Carriage Ensemble
LCPL	Lance Corporal
LEA	Land Engineering Agency
MAULER	Multi-role Autonomous Land Experimental Robot
MEAO	Middle East Area of Operations
MULE	Multifunction Utility/Logistics Equipment vehicle
NATO	North Atlantic Treaty Organization
NCO	Non-Commissioned Officer
NVG	Night Vision Goggle
OR	Other Ranks
RAR	Royal Australian Regiment
SOP	Standard Operation Procedure
UGV	Unattended Ground Vehicle

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1. Introduction

The equipment carried by today's Infantryman is so bulky and heavy that it presents a significant burden and impairment to his performance, both when training and on operations (Polcyn et al. 2002; Milanese et al. 2000). The problem of an excessive equipment burden is widely recognised within the Australian Defence Force (ADF) (Bonner et al. 2007; Paulson 2006) and significant effort has gone in to addressing it, from such diverse fields as equipment design (Bossi & Tack 2001), soldier training (Rudzki 1989), the logistics chain (Allan & Vanderpeer 2007), and robotics (Fielding 2006; Milanese 2006). Despite this effort, the Australian Infantryman is still required to carry weights often greater than 50 kg (see Section 2.5.7) for significant distances. With plans in place to introduce even more equipment to the soldier's ensemble in the future through various ADF projects such as Australia's Soldier Modernisation Programme (Project LAND 125) a characterisation of the problem, a review of the causes and an examination of potential solutions is needed.

Figure 1: A Section Commander in Marching Order

An Infantryman's load consists of the contents of his backpack and webbing, as well as his uniform, boots, combat body armour, helmet, plus weapon, ammunition, and accessories mounted on the weapon. The content of his pack includes standard required equipment as outlined by the unit's Standard Operational Procedures (SOP), as well as personal rations and 'morale' items. Usually a soldier must also carry additional section or platoon assets including radios, batteries, claymore mines or medical stores. Often the soldier is required to perform rigorous physical and mental tasks whilst carrying this equipment (Fig. 1).

The soldier equipment burden is an easily identified problem, one that has been recognised by Armies around the globe and described many times over in periodicals, journals and conference papers (for a summary see Knapik 2004). A review of the literature confirms that a great deal of effort has gone in to evaluating this problem. However, this report will show that despite all the work to date no single effective solution has arisen.

This is not to say there is no way to address the problem of soldier load carriage. There are solutions, but they are many. In and of itself each solution may have only a small impact, but taken together they can combine to lift the equipment burden off the soldier's shoulders and allow him to do his job to the best of his ability.

1.1 Report Aims

The aims of this report are to characterise the problem of soldier excessive load carriage, to assess the impact the equipment load has on soldier performance, and to provide recommendations from a range of disciplines to reduce the soldier's burden.

1.2 Report Structure

The authors of this report seek to describe a number of solutions and put them in the context of the *soldier equipment burden*, a descriptive framework which itself will be described in detail. The report is in three parts;

- Part One, titled *A Soldier Equipment Survey* aims to characterise the soldier's load by providing a real-world snapshot of the type, weight and manner in which the load is being carried by the Australian Infantryman, and capture recommendations from users for pack and webbing design improvements.

- Part Two, *The Problem of Soldier Load Carriage,* contains a description of the issues contributing to the excessive soldier load and the consequences of this load. A usable definition of the Soldier's Equipment Burden is then outlined from which solutions in Part 3 are based.

- Part Three, called *Near Future Solutions,* contains a review of various approaches to address load carriage from a number of different fields of R&D, including equipment design, mission planning and assistive technologies. Together these approaches offer a suite of realistic near-future solutions to the problem of the soldiers' equipment burden.

2. A Soldier Equipment Survey

2.1 Introduction and Objectives

In February 2006 a survey of Infantry equipment was carried out by staff from the Defence Science and Technology Organisation (DSTO). The researchers (comprising a Human Factors Scientist, Industrial Designer and ARA Infantry Captain) visited three regiments (2 RAR, 6 RAR and 5/7 RAR), interviewed soldiers and examined packs, webbing and their contents. All soldiers interviewed had packed for a 72 hour patrol. The overall goal was to obtain a real-world snapshot of the equipment regularly being carried by the Infantryman in their Load Carriage Ensemble (LCE).

Specifically, there were six objectives to the survey:

1. Examine the type and setup of the LCE being used,
2. Compare the LCE contents with unit SOP load lists,
3. Determine levels of discomfort when wearing the LCE,
4. Identify how the LCE is being packed and the reasons for this,
5. Obtain real-world soldier weights & load weight, and
6. Determine compatibility issues with the LCE.

A questionnaire was developed (see Appendix A) that the researchers used to examine the objectives mentioned above. The information was collected using the structured interview technique whereby a researcher sat one-on-one with each soldier and went through the questionnaire list with them. Often the soldier's pack and webbing was present and examined during the interview to help the soldier clarify issues raised. The questionnaire was designed so that responses could be recorded as numbers, descriptions, or drawings, as appropriate to each question.

2.2 Participant Demographics

In total 66 soldiers were interviewed including 19 dismounted infantry from 2RAR, 40 mechanised infantry from 5/7RAR and seven motorised infantry from 6RAR. Only males are permitted within the Australian Infantry, so all data collected were from men. Some non-identifiable information about each interviewed soldier was recorded (age, rank, years in service, role in platoon). As illustrated in the data below, the years in service and rank distribution is fairly typical of the numbers of Non-Commissioned Officers (NCO) and Other Ranks (OR) found in a rifle company. In reviewing the results presented here it should be noted that there were more soldiers interviewed from mounted and motorised infantry units than for dismounted infantry; the latter generally considered to have the highest equipment burden since they do not rely on vehicles to re-supply or store items.

2.2.1 Years in service

About one third (19) of those interviewed had been in the Army for less than one year. Very few (5) had been in for more than six years (Fig. 2). Some of the soldiers had deployed to the Middle East Area of Operations (MEAO), and so their feedback was considered particularly relevant and useful as it is likely the lessons learned about load carriage when deployed are of significance to all combat arms, regardless of operation type.

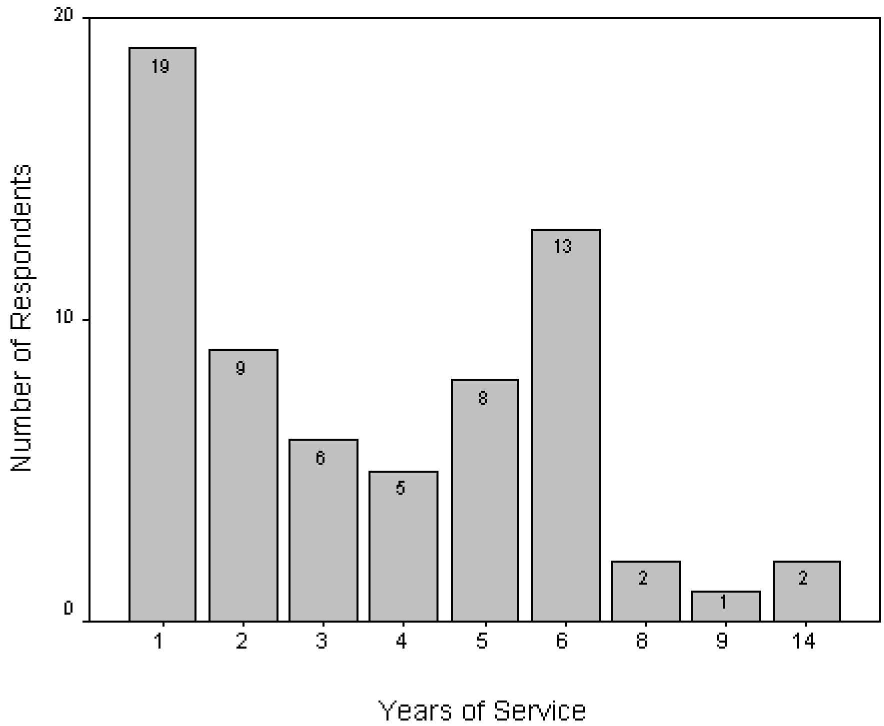

Figure 2: Years in Service (rounded up to the nearest whole year)

2.2.2 Rank

The information presented in Table 1 outlines the number of soldiers within each unit interviewed, and what rank they held.

Table 1: Number of Respondents by Rank and Regiment

Regiment	Private	Lance Corp	Corporal	Sergeant	Total
2 RAR	11	5	2	1	**19**
5/7 RAR	34	5	1	-	**40**
6 RAR	5	2	-	-	**7**
TOTAL	**50**	**12**	**3**	**1**	**66**

2.2.3 Main Role

All soldiers interviewed were asked to describe their main role within their Company. The results are summarised in Table 2. Two soldiers (one rifleman and one scout) also carried a Grenade Launcher Attachment (GLA). Three soldiers did not describe their roles.

Table 2: Main Role within the Company

Position / Role	Number
Rifleman	23
Gunner	8
Scout	8
Section 2IC	11
Crew Commander	3
Section Commander	3
Signaller	6
Platoon Sergeant	1

2.3 Type of Load Carriage Equipment

2.3.1 Type of Pack

Soldiers were asked if they normally used the pack that had been issued to them (the 2006 LAND 125 Field Pack Large). The results are presented in Table 3. In total 37 of the 66 respondents used the issued pack. However, the 19 soldiers from 2RAR had been instructed to wear the issued pack. If 2RAR members had been given the choice as to what pack to wear then the trend suggests the number of those wearing the issued packs may have been lower than observed. By comparison, Jaffrey et al. (2008) noted that 44% of soldiers interviewed from 3Bde purchased their own pack and frame.

Table 3: Number of respondents who used the issued Field Pack

Regiment	Own	Issued
5/7RAR	20	20
6RAR	7	0
2RAR*	2	17

*** Of the two soldiers from 2RAR that didn't wear LAND 125 kit one was a CPL section commander from a mortar platoon and the other was a LCPL rifle section 2IC**

Of the 29 soldiers who used their own pack, 27 had packs with an external frame (Fig. 3). The packs being issued by Project LAND 125 now have an external frame but this pack had not been issued to these soldiers in 2006. Not all respondents knew or reported the brand of their own pack, but of those that did, the *Platatac* brand packs were the most common.

In summary, there was a strong preference for an external frame pack, and a significant trend for soldiers to purchase their own load carriage packs.

Figure 3: Soldier wearing his non-issue external frame pack

Eighteen soldiers had customised their packs, either the issued packs or their own. The most common customisation was the addition of an external frame (normally an ALICE[1] frame). Some soldiers added padding to their pack shoulder straps, or replaced them with commercial products. Two soldiers had sewn a zip into the bottom of their pack in order to allow easy access to their sleeping bag.

Two thirds of soldiers did not have a belt attached to their packs. Of the one third that did have a pack belt, only half of them used it. Only one in six soldiers (17%) used a belt to help support their pack weight. Frequently soldiers commented that they did not wear the belt on the pack because it interfered with the webbing and took too long to unclip when the pack needed to be removed in a hurry (such as during a contact drill). By comparison Jaffrey et al. (2008) found only 6% used the pack belt.

Soldiers were asked to make additional comments on packs. Some reported that the external frame packs were more comfortable, were less restrictive and provided better support of the load than packs without external frames. Infantry involved in mechanised operations often mentioned that a smaller 'sniper pack' would be preferred due to limited load space inside the vehicle.

[1] ALICE: All-purpose Lightweight Individual Carrying Equipment

2.3.2 Preferred Size of Pack

Some soldiers, particularly those from 5/7 RAR, had a field pack and a smaller 'sniper' pack which they used for in-vehicle work. Some of these soldiers commented that their sniper pack was always full but not the field pack. Some others also commented that this was dependent upon the weather; if it was warm then there was little need for cold weather gear, which reduced the volume of the load noticeably. One soldier also commented that it was not more volume the soldier needed it was more accessibility. See Section 4.3.2. on strategies to address this issue.

2.3.3 Type of Webbing

Soldiers were asked if they normally used the webbing that had been issued to them. Of the 66 respondents 34 of them used non-issue webbing (Table 4). As with the packs, the soldiers from 2 RAR had been ordered to wear the issued webbing. Jaffrey and colleagues (2008) had similar results with 3Bde in 2004; noting that about half of soldiers interviewed used hip webbing.

Table 4: Number of respondents who used the issued Webbing

Regiment	Own	Issued
5/7 RAR	24	16
6 RAR	7	0
2 RAR	3	16

Not all respondents knew or reported the brand of their own webbing, but of those that did, the *Platatac* brand webbing was the most common, followed by the *Arktis* brand.

Table 5: Number of users per webbing type

Webbing Type	Number of users (% of total)
Battlebra	8 (11%)
Chest	34 (45%)
Hip	15 (20%)
Chest and Hip together	11 (15%)
Not recorded	7 (9%)

Soldiers were asked what type of webbing they mainly used. The results are detailed in Table 5. Chest webbing was the most common webbing type. Although soldiers from 2RAR were required to wear the issued webbing, that webbing could be configured as either chest webbing, hip webbing, or together as a combined chest and hip rig. Eleven soldiers wore the hip and chest webbing together. It was not the intent of the LAND 125 design for soldiers to wear *both* chest and hip webbing together, mainly due to increased weight and reduction in manoeuvrability of the soldier that result. A number of soldiers had more than one set of webbing. Some 11% wore a 'Battle Bra' (Fig. 4).

Soldiers generally personalised their webbing configuration; placing pouches at preferred locations and tying off straps to best suit their body shape. Some had gone further and made alterations to the actual harness. The most common customisations included the addition of 6-point harnesses (Fig. 4) or a second comforter belt (Fig. 5).

Figure 4: Soldier wearing 'Battle-Bra' webbing with 6-point harness modification

Figure 5: Hip Webbing with additional comforter belt

Soldiers were asked to make additional comments on the webbing. Some reported that hip webbing was not appropriate when in a vehicle (APC/ASLAV/Bushmaster) as there was not enough room in their seats for the pouches, and the risk of snagging their webbing on some fixture in the vehicle if the soldier had to debus rapidly. However hip webbing was preferred by the gunners (F89 operators). It was also mentioned that hip webbing moved about too much if running (which causes discomfort [see 2.4.2.] and reduced agility [see 3.1.1.]). This observation is supported by previous work commissioned by DSTO (Milanese et al. 2000).

2.3.4 Discussion

Many soldiers wore packs that had not been issued to them. The main reason for this was the desire for a pack with an external frame. However, the packs now being procured by Project LAND 125 for soldiers do have an external frame.

Considerable research into the ergonomic aspects of the pack frame has taken place (including Milanese et al. 2000). The advantage is that frames remove much of the weight off the shoulders and transfer it lower down on the body, improving support by the waist. Also, the gap formed between the pack and the wearer's back allows air to flow which increases heat transfer away from the body. In reality however, many soldiers fill this gap with equipment, particularly sleeping gear. It should be noted that the framed pack increases the gap between the load weight and the wearer's Centre Of Mass (COM). The difference between load COM and 'natural' COM should be as small as possible (Knapik et al. 2004) to ensure economical energy expenditure when carrying loads.

Wearing a chest webbing rig or battlebra often sets the body centre of mass higher than if wearing hip webbing. Problems of fatigue may emerge if the COM is higher than the soldier's natural COM. Milanese and colleagues (2000) noted that positioning some webbing pouches posterior to the body's COM when wearing just webbing reduced the impact of the webbing weight on posture and muscle strain. In the same study a pack with an ALICE frame coupled with hip webbing impacted the soldier the least when stationary but an internal framed pack with chest webbing impacted the soldier the least when he was performing dynamic activities. Similarly Coombes and Kingswell (2005) noted that chest webbing is more energy efficient during running than hip webbing. The best position of the load is high on the body when the soldier is moving on flat ground, but a low to middle load configuration is best when the soldier is on uneven terrain (Knapik et al. 2004). These results suggest that there is no one best pack combination and if there are to be multiple LCEs per soldier they should perhaps be divided according to the type of work he is performing.

This survey identified that only one in six soldiers wore the pack belt. Many of those who didn't wear the pack belt commented that the belt took too long to remove and sometimes was in the way of their webbing. However, the pack belt is a significant ergonomic aide to the soldier. The belt helps secure the load from moving and helps transfer some of the load from the shoulders to the hip (Knapik et al. 2004) which is beneficial to the soldier. There is a need to develop a pack belt that soldiers will wear, either as a single replacement item (e.g. with a quick release buckle) or as part of an integrated load carriage ensemble. There may also be a need to change soldiers' perceptions of the pack belt.

There are potential problems with the practice of soldiers buying their own equipment. Firstly, the kit may look suitable in the store or on the website but non-issued kit has not been tested and passed by the Army's Design Authority: the Land Engineering Agency (LEA). Similarly, no scientific inputs into the design and the materials of the LCE have been provided by DSTO. Furthermore, there is no support for personally procured equipment when deployed or in the field training. One possible means to support the soldiers' practice of buying their own load carriage kit is to develop a short list of approved items from which the soldiers can choose the equipment they prefer.

2.4 Load Carriage Ensemble Interface & Discomfort Issues

2.4.1 Interface Issues

Soldiers were asked to describe any compatibility problems with their load carriage equipment. Some soldiers reported no problems at all but the comments that were received are listed here. These comments aid in characterising the problem but do not necessarily represent the views of the majority of the soldier population.

- The webbing comes in contact with the pack, which causes one of two problems:
    - the hip webbing overlaps with the lumbar support of the ALICE frame causing discomfort and potential injury through skin abrasion,
    - the pack pushes down on the back of the hip webbing, forcing the webbing to roll backwards, making it difficult to reach items in the rear webbing pouches.
- Pouches and water bottles can collide with the pack when walking. This can make undesired noise.
- Soldiers often cannot raise their head to sight through their weapon when prone with pack and webbing on as the pack pushes forward on the back of the head, making it difficult to raise the head, or pushes the helmet down on the face.
- Winter weight sleeping bag can sit sideways in pack and make the load asymmetrical, putting excessive pressure on one shoulder and one side of the hip.

2.4.2 Discomfort

Soldiers reported less back pain with external frame packs than the unframed field packs. No soldier complained of muscle soreness of any type during this review. The main injuries reported resulted from contact between the LCE and the body. The most common complaint was rubbing and chaffing. The LCE dug in at various locations and cut the skin, causing bruising and blisters.

Other issues of discomfort and injury were reported: heat rash was common, as was numbness of the arms from the constriction/pinching of the nerves in the shoulders. These observations are regularly reported in the literature (Knapik et al. 2004, Bonner et al. 2007, and Jaffrey et al. 2008).

Discomfort is fatiguing. Discomfort is also a distraction to a soldier on operations and can be an indication of a potential injury if not attended. As such it is important to address discomfort when it arises, and not train soldiers to 'tough it out' if the problem can be corrected. A soldier's body moves about more than the pack and webbing to which it is strapped. This discrepancy is the cause of much rubbing and chaffing. The basic solution is to reduce the friction between the skin and the pack. This can perhaps be done by adding a low friction material between the two surfaces, or by redesigning the LCE to move in unison with the soldier. A pack design that moves with the wearer may also reduce the energy required to carry it. It has been suggested by suppliers that a malleable plastic pack frame provides movement to aid the soldier, though structured biomechanics testing is required to confirm this.

2.5 Content of LCE

All infantrymen were asked to describe the total number and volume of different items in their LCE. Some of these items were not present during the interview but the soldiers said there was little variation between missions for these items. As is typical, all soldiers had equipment packed for 72 hour operations.

It should be noted that since this data collection was carried out in 2006 some items that were not on SOP lists are now Government Furnished Equipment (GFE) and are issued to soldiers.

2.5.1 Amount of Water

The majority of soldiers carried two litres of water in their webbing (or *Camelback*™) and eight litres in their packs. There was some variation in this, with some carrying more. The total weight of 10 litres of water is 10 kilograms, plus the weight of the various water storage containers.

2.5.2 Amount of Ammunition

Typically F89 Gunners carried 800 linked rounds, of which 500 was carried on their webbing, the rest given to another soldier to carry or (occasionally) in their packs. Total weight of 800 linked rounds is 10.8 kilograms.

The most common volume of rounds carried by those using the F88 rifle was 210 rounds (seven magazines). A few Section Commanders plus others carried from one to seven additional magazines. All ammunition (except perhaps those carrying large additions) was carried in webbing. Total weight of 210 rounds is 3.5 kilograms.

2.5.3 Amount of Rations

The average amount of rations carried was 3 days' worth. The majority of soldiers broke down their ration packs. Typically only one meal and/or snacks was stored in the soldier's webbing, the rest was in the pack. When the ration packs are broken down some items are normally discarded (Forbes-Ewan, 2001). The items discarded are usually done so because the soldier did not want to eat them, and not specifically because they were considered too heavy. Combat rations typically weighs 1.8 kg per soldier per day when complete. Patrol rations (aka 'dehyd' rations) typically weigh 1.1 kg per soldier per day when complete.

Note that water must be carried in addition to the patrol rations to re-hydrate them. Total weight for three days of combat rations is 5.4 kilograms.

2.5.4 Issued but not Carried

All soldiers' loads are determined by a unit SOP list. Soldiers in this study were asked if there was any equipment on their SOP list that they regularly did not carry with them, and why. There was only a small amount of kit from the SOP list not packed (Table 6). The bayonet cannot be used by soldiers with the underslung GLA, so they do not carry it with them. Many soldiers do not carry their mess kit, since most rationed food can been prepared and eaten without it. Quite a number of soldiers reported not carrying their issued sleeping bag. If the weather is warm then no cold weather kit was packed. Often no spare uniform is packed if the soldier is to be away for only 72 hours.

2.5.5 Alternative Version of Issued Kit

Soldiers were asked if they replaced GFE with their own personally procured items. Table 7 has a list of all reported non-GFE carried. Many soldiers did not carry the issued sleeping bag because it was considered bulky and heavy. The preferred alternative was the *Merlin Softie*™ series of sleeping bags, which was considerably smaller and lighter, and reportedly offered the same (if not better) heat insulation.

Some used non-issued versions of the raincoats, though no reason was given for this. Many soldiers also used a *Maglite*™-brand torch instead of the issued utility torch. The Maglite was supposedly brighter, lighter and smaller than the issued torch. Many soldiers carried a *Leatherman*™ or some other utility knife. *Ka-bar*™ knives were often carried also.

2.5.6 Additional Kit Carried

Many infantrymen carried additional equipment; kit that is not on the SOP list. The most common was the *bivvy bag*, which is a weather-proof outer to the sleeping bag. Camelbacks were also used by the majority of soldiers. Some also carried umbrellas, gas bottles and burners for added comfort when in the bush.

Table 6: List of reported equipment not carried (left), replaced (middle), and in-addition to the SOP list (right)

Issued but not Carried	Alternative Version of GFE	Additional Kit Carried
Bayonet	Cam cream (alt type)	Bivvy bag
Cold Weather Uniform	Gun oil bottle (larger)	Caribena
Pan Mess Kit	Knife (combat)	Gas bottle & burner
Sleeping Bag	Knife (utility)	Pegs
Spare uniform	Mozzie Repellent	Torch (head light)
Towel	Raincoat	Umbrella
	Softie sleeping bag (*Merlin*)	Plastic Entrenching Tool

Some items were listed by soldiers as personal equipment but are now (or are soon to be) issued items. These include the *Camelback* and any additional water bladders, the *Silva* compass, the large (2 litre) water bottles and *Maglite* torches.

2.5.7 The Current Load

This report is not aiming to prove there is a soldier load carriage problem. The problem is so prevalent that no further proof is considered necessary; and previous studies have addressed this issue sufficiently (Knapik 2004; Allen & Vanderpeer 2007). Whilst there is no need to exhaustively list measured weights, and since the load distribution varies between Battalions, Platoons, and even soldiers, it will be useful to determine the average current weight for issues discussed in this report.

The weight of the equipment the infantryman must carry often exceeds 50 kg, but this has not always been the case. Knapik et al. (2004) reviewed data on the weights carried by soldiers throughout history. It is clear that the modern dismounted infantryman must carry a weight greater than soldiers in past conflicts. Part of this increased weight is because there is reduced auxiliary transport so the soldier must carry their own equipment. In fact, a key advantage of the dismounted infantry is that they can penetrate where support vehicles can't follow.

Load weight has also increased as the capability of the soldier has increased; the soldier can now do more by utilising new equipment previous generations of soldiers did not have access to. However, it is likely that the equipment burden has now increased to the point where capability is compromised. As Paulson (2006 p.81) notes; 'the weights carried at the moment are incongruent with the notion of manoeuvre warfare'.

Numerous studies have reported the weight carried by soldiers from various countries in different conflicts. The results of this survey are compared to previous studies in Table 7. It is important to acknowledge that the weights carried changes over time as food is consumed, water drunk and ammunition used (especially during training). As such a full load does not remain full for long and weights quoted are often full loads.

Table 7: The Weight (in kg) of Soldier Equipment by survey

Load-out	Description	Duration worn	SOP[2]	Land 125 SOP[3]		Survey[4]	
			*averaged**	Rifleman	Gunner	Rifleman	Gunner
Light Patrol	Webbing Only	8hr	-	24.9	38.3	-	-
Patrol Order	Webbing & Day Pack	8-24hr	37.7	34.7	48.1	-	-
Marching Order	Webbing & Field Pack	24-72hr	60.2	50.9	64.3	46.0	57.0

*averaged over the section

In summary, although there is some difference between soldier roles and operations, in general it is likely that *55 kg is typical marching order weight and 35 kg is a typical weight for patrol order on a 72 hour operation.*

2.5.8 Summary

One objective of this survey was to identify items recommended by soldiers that performed a role similar to a piece of GFE, but was lighter and/or smaller. Besides the pack themselves, which are discussed above, a plastic folding entrenching tool (ET), which was lighter than the issued item and took up less room when folded (Fig. 6) was being packed by soldiers. Other items noted included the *Merlin* brand sleeping bags and water bladders instead of the green plastic canteen bottles.

Figure 6: Folding Plastic Entrenching Tool

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[2] 2 litres of water for patrol order. 4 litres of Marching order (though 3 days rations and ammo).
[3] 8 litres of water for marching order. 4 litres for patrol order. 2 litres for light patrol order. From the Land 125-01-02 (MAR 02).
[4] Includes typical load: Pack webbing and contents. 10 litres water, 3 days rations, front line ammo & weapon Excludes section and platoon level equipment: radios, med kits, batteries, GPS, binoculars & NVG.

2.6 How LCE is packed

All soldiers were asked to comment on where they packed various items in the pack and webbing. The results are summarised in Table 8.

Table 8: Most common location different items were packed

ITEM	LOCATION PACKED
Water	• All soldiers carried water in their webbing + additional water in packs • The water carried in packs was normally placed on the outside pouches • Some carried water at the very top of the inside of their packs
Rations	• Rations were distributed evenly between the inside and outside pack • When packed outside most rations were on the top pouches • Ration packs inside the packs were generally at the top
Helmet and CBA	• Helmet was normally attached to the outside of pack • Typically at the upper back, or on top • CBA rarely stored in pack, except admin moves. Normally worn.
Ammo	• If extra ammo was carried in the pack it is inside, at the top • Only a small minority of soldiers reported carrying ammo in their packs
Sleeping kit	• Included sleeping bag, blanket and bivvy bag • These were typically carried at the inside very bottom of the pack

2.6.1 Why pack this way?

When asked why they packed this way, most soldiers commented that easy access to the important items was the main reason. Comfort was often mentioned, but was normally a secondary concern. One soldier summarised their packing strategy well; 'I live on the outside of my pack'. Because soldiers required quick access to items they used most often (water and rations) they packed them in the outside and top pouches of the pack.

By using this packing strategy the amount of equipment that is removed from the pack at any one time is minimised. This allows the soldier to respond to any unforseen incident without having to repack (or leave behind) everything in their pack. This is a basic rule for the infantryman that has been taught throughout training.

2.6.2 Suggestions for Improvements

The soldiers were given an opportunity to describe ideas for improving their load carriage equipment. Details are listed in Table 9. The following list is to aide in characterising the issue of soldier load carriage, but the items are not necessarily indicative of the majority of soldiers. This list is also not a critique of any one pack type, but a recommendation for preferred pack designs.

Table 9: Soldier Recommendations for LCE Improvement

Suggestion	Details
An External Frame	• An external frame was desired by some of those who did not already have one on their pack
More External Pouches	• In keeping with the "live on the outside of your pack" philosophy some soldiers requested more external pouches for the pack
Highly Adjustable Pack	• In order to improve comfort (and reduce injury) some soldiers asked for more adjustability of the pack to suit the full range of body sizes
Expanding/Stretching Packs	• Although not all agreed, there was the suggestion that the packs be expandable and stretchable • The advantage of this is that the load in a half-full pack would be more secure and less likely to move about when the soldier is walking • The disadvantage is that soldiers may be inclined to add 'just one more' item to the pack until breaking point
Modular Pack	• It was suggested that the full field pack be broken down into a smaller pack for mechanised operations • This would mean the soldier would not need two separate packs and so would not need to swap equipment between the two dependent upon the operation
Pack/Webbing Made of Lighter Material	• The pack and webbing when empty weighs about 6 kilograms • Soldiers suggested that if they were made of a lighter material then it would reduce the total weight the soldier carries • A lighter pack that is replaced more often was considered reasonable option
100% Waterproof Pack and Webbing	• A waterproof pack and webbing • When the pack is wet, and water enters the inside of the pack, not only is there a risk of damage to the contents, but the total load is increased, since the water itself must now be carried. • Note that the weight of the water-proofing material may make this option non-viable

In summary, the soldier's load is their 'workplace' and they spend a lot of time ensuring it is in good working order. An ideal solution to improving the LCE is to combine soldier's comments/suggestions with ergonomists recommendations and knowledge from equipment designers and materials experts.

2.6.3 Summary

The volume of the total load and the way the load is distributed within the pack is an important issue since an asymmetrical load will put an excessive burden on one side of the body, increasing the likelihood of discomfort and injury. As will be discussed later in this report, the centre of mass of the load should be as close as practicable to the body's natural COM. This is more likely to happen if the heaviest items are as close to the lower back as possible. There is of course the issue of accessing important items quickly, which is why these items (usually the heaviest unfortunately) are packed on the outside of the pack. Possible solutions to this issue will be addressed in Part 3 of this report (*Near Future Solutions*).

2.7 Recommendations

- Soldiers had a strong preference for an external frame pack and a willingness to purchase their own equipment if they considered the GFE unsuitable. So there is a need to ensure any load carriage equipment in use by soldiers carrying heavy loads has received both engineering approval (i.e. DMO) and ergonomics testing (i.e. DSTO).

- There is a need to address the pack belt issue by redesigning it, reducing interface problems with other equipment, and improving soldiers' compliance in wearing pack belt.

- Soldiers 'live on the outside of their pack'. Soldiers pack for need first, ergonomics second. Since many high-need items are also the heaviest there may be a need to re-consider pack design with these factors in mind.

- The weights carried at the moment are incongruent with the notion of manoeuvre warfare, and soldiers experience discomfort and injury from their LCE when carrying heavy loads, so the need to reduce the equipment burden should reduce the risk of injury and improve performance.

- A smaller 'Sniper Pack' may be more suitable for vehicle-based operations.

3. The Problem of Soldier Load Carriage

3.1 Consequences to the Soldier of Carrying an Excessive Load

Why is it there is such concern about the heavy equipment loads a soldier must carry? This section outlines an argument that the overall consequence to the soldier of carrying such a burden is that their performance in many tasks is compromised. Performance is compromised because the equipment burden impacts on soldier *agility*, creates *fatigue*, and increases the risk of *injury* and hence behaviour on the part of the soldier to avoid injury. These three factors impact on the North Atlantic Treaty Organisation (NATO) categories of survivability, sustainability, lethality and mobility.

3.1.1 Agility

A previous DSTO study demonstrated that a soldier's overall load reduces his agility (Milanese et al. 2000). The bulk and weight of the load impacts the soldier's speed, mobility and coordination. The soldier's centre of mass is shifted and tasks such as moving up and down slopes, crossing obstacles and completing a basic drill are all significantly more difficult to perform. The load also moves about when the soldier moves and this further destabilises the soldier, which in turn requires extra effort to steady himself. All these factors negatively impact on the NATO category of survivability since it takes longer to reach cover and a slow moving target is easier to hit by enemy fire.

Similarly, the NATO category of lethality is negatively impacted as changes in posture, brought about by carrying a heavy load, can negatively impact fine motor control. Fine motor control can reduce aiming performance of a rifle, or even guided anti-armour or anti-aircraft munitions. As such, improvements in load configuration can minimise the impact of this load on the soldier's agility (Milanese et al. 2000). An optimal load carriage system will seek to minimise the amount of muscle effort required to carry the load. Muscle effort is determined by total weight as well as weight distribution on the body.

3.1.2 Fatigue

Fatigue is characterised by muscle weakness and reduced coordination. Fatigue can produce deficits in cognitive performance such as decreased reaction time, vigilance, memory and logical reasoning (Lieberman et al. 2005). Fatigue results from a number of factors, including dehydration, lack of nutrients and energy loss as a result of physical exertion. Energy expenditure when carrying a load is determined by slope, speed, terrain type, body weight, load weight and load distribution (Davy and Demczuk 2003).

Although being fatigued may be uncomfortable and perhaps undesired, in and of itself being fatigued is not an unexpected state for a soldier to be in. While it is self-evident that a 75 kg soldier carrying 50 kg of equipment is going to become fatigued quickly, studies by DSTO have shown that carrying typical soldier equipment weights is fatiguing for all soldiers, regardless of their body weight (Milanese et al. 2000).

3.1.3 Injury

Short or long term injury during training or during operations can render the soldier unfit for his trained profession and has a direct impact on unit sustainability. Injuries during deployment may require treatment which reduce operational tempo. Such a casualty is absent from their unit and their care incurs a cost to the Department. There is also the possibility that a replacement must be trained.

The risk of injury to the soldier is higher when carrying heavy loads (summarised in Milanese et al. 2000). Load carriage has been identified as a risk factor for musculoskeletal injury, including *brachial plexus palsy* (damage to the nerves that control arm movement) and low back pain. Foot blisters and skin conditions are also common, as well as *Metatarsalgia* (foot pain or 'Stone Bruise'), stress fractures and knee pain (Knapik et al. 1996).

Carrying a heavy backpack and webbing imposes problems on the soldier's posture. The degree of postural change following the application of a load may be responsible for a number of reported load carriage injuries. As described in Section 2.4.2. (*Discomfort*) soldiers report that a heavy load can put pressure on the skin, which produces health issues including chaffing, muscle strain, and heat rash. A recent review of CBA and LCE also found frequent complaints of such injuries (Bonner et al. 2007). Carrying a load impacts the way a soldier stands and walks (their *gait*) (Harman et al. 2000; Milanese et al. 2000 & Milanese 2006).

3.1.4 Performance

In summary, a heavy equipment burden can reduce a soldier's agility, produce fatigue, and increase the likelihood of injury. Any of these limitations can negatively impact on a soldier's ability to perform his role on the battlefield.

3.2 How Heavy is 'Too Heavy'?

What is the maximum load a soldier can carry? This question is raised frequently in Defence Procurement Meetings and S&T forums, but it is difficult to provide a simple answer. The question is difficult to answer because the question is too general and incomplete. A more suitable question would be:

What is the maximum load a soldier can carry…

… and still be ready to fight immediately after a 15 km march?
… maintain blood flow to the arms?
… climb a mountain in Timor Leste without injury?
… avoid the risk of rucksack palsy after a 6 month deployment?
… allow a soldier to stand from sitting unassisted?
… carry out operations in high heat, high humidity conditions?
… when travelling at x km/hr over a y° gradient for z minutes?

Specific questions are needed, which take in to account the role of the soldier, and the environment they are operating in.

Simply put there are so many different roles for a soldier, in so many environments, that an accurate answer is difficult to give without first defining some of the limitations that should be placed on the soldier. As identified above (Section 3.1) the excessive load a soldier endures decreases their overall performance by reducing agility, accelerating fatigue, and increasing the chance of injury. So there is a need to determine how much freedom of movement (agility) is required by the soldier to allow him to perform his various tasks. There is a need to decide how much fatigue is acceptable, and the level of acceptable injury risk in order to complete the task at hand. How much of a reduction of agility, level of fatigue and risk of injury is considered acceptable for the soldier to tolerate?

The most straightforward way to determine an acceptable level of performance loss is to decide upon minimum required performance for agreed-upon scenarios and determine what weight is possible to maintain that performance.

In summary it may be possible to answer the question of *what is the maximum load a soldier can carry?* but only after acceptable limits to agility, fatigue and injury risk are set.

3.3 Performance Benefit From Carried Equipment

An assessment of the soldier's equipment burden should not just consider the negative impact the load has on agility, fatigue and injury risk, but should take into account benefits the equipment provides to the soldier. Obviously each piece of equipment a soldier carries helps him perform his many tasks and, since they are carried, they are available for use without having to wait for supply.

One way to reduce the soldier equipment burden is to remove items from the soldier's kit. The obvious consequence is that the item will not be convenient when needed, and as such performance on the task is reduced, or becomes unachievable.

The exact problem is that we want the soldier to have access to the equipment when needed without reducing agility, accelerating fatigue or at risk of injury to do so beyond established acceptable level. So, is it possible to reduce the soldier's burden while at the same time ensure the equipment the soldier needs is available when needed? Some possible future solutions are addressed in Part 3 of this report.

3.4 How is the Soldier's Load Determined?

Regimental SOP dictates the majority of the equipment each soldier carries. Soldiers also carry equipment given to them by their section members, by the platoon and sometimes company assets. Commander's instruction may also add operationally-specific equipment.

Each soldier will almost always carry some 'jack-rations'[5] with them, especially for longer patrols. Some will add comfort items like umbrellas and gas bottles also.

Regimental SOP for soldier equipment are very general in regards to the type of operation for which they kit the soldier. Paulson (2006) suggests that the SOP should be considered as a guide only, since there is inevitably equipment carried but never used.

There are competing priorities in the development of the soldier's equipment loadout. Some of these do not align with the soldier's need to reduce their load, and there is often little overall co-ordination. It is not unheard of for a project to set an arbitrary weight limit to be included in the functional performance specifications for any new piece of equipment. This seems a logical strategy. However, any weight increase should be linked to a corresponding increase in capability. There should also be ergonomic or biomechanics evidence that this new weight is tolerable, and studies on capability development that the additional weight is justified. Even a small weight increase soon adds up when we consider the amount of new equipment the soldier is being required to carry.

Rapid acquisitions to meet urgent operational needs are becoming frequent occurrences, with less time and effort available to review all consequences the proposed new equipment has on the soldier, weight is rarely considered a 'show-stopper' issue. Perhaps what is really needed is a pervasive philosophy that the size and weight of new equipment be given highest importance during the acquisition phase, by showing a direct link between weight and performance (see Davy and Demczuk (2003) for a good example of this).

3.5 The 'Weight Budget'

One strategy to deal with the issue of an excessive soldier's load, and to control the disparate groups within the Department of Defence all attempting to add more to the pack, is to prescribe a weight budget for each member of an infantry section. Such a strategy has been adopted by many modern military forces. The benefit of such a solution is that it is straightforward and easy to understand. As an example the US Army Objective Force Warrior program aimed for 22 kg load and Future Force Warrior Program: 18 kg for infantryman, 27 kg for commander.

This weight budget is given either as a specific weight or as a percentage of body weight. The disadvantage with the percentage of body weight method is that designing for many different weight targets increases the complexity of the problem. Also, it is likely to be difficult to police or enforce any percentage weight limit.

For a fixed or percentage weight budget solution to be implemented some kind of centralised project control over the soldier's load is required. As can be seen from section 3.4 above, this is not a small undertaking. The project must not just oversee but have control over the weight carried by the soldier. This may not be as difficult when dealing with future systems, since they are often designed as ensembles, but the contemporary

[5] Non Army issued rations, typically snacks procured by the soldier.

soldier has additional equipment added to his load by his regiment, company, platoon section members and himself. As such the weight budget becomes difficult to put into practice. The adoption of a single weight budget may also further 'generalise' the soldier's load, requiring him to carry all on his load list even if not needed.

There are other considerations that must be addressed when adopting a weight budget strategy. Firstly, to determine the weight budget requires an answer to the question raised above: *how much is too heavy*? As we have already determined this question is context dependant. Secondly, a single weight budget that encompasses all operational needs is likely to be too general. Also, weight is not the only consideration when loading out a soldier, there is total volume of the equipment and duration of carriage that must also be taken into account (see Section 3.6).

3.6 Burden = Weight + Placement + Duration

The absolute weight of any piece of equipment is only one issue to be considered when examining the problem of soldier load carriage. The equipment burden can more accurately be characterised if equipment weight, load placement and carriage duration are all considered together.

3.6.1 Weight

The equipment survey summarised in Section 2.5.7. noted that the average weight for a rifleman is 46 kg and 57 kg for an F89 gunner. This weight is at the start of a mission (with a full load) but minus any section, platoon or even company assets.

3.6.2 Placement

The way an item is carried can have as much of an impact on the soldier as the actual weight. Carrying 10 litres of water is easier when it is secured in a pack than when it is in a jerry can carried by hand. Similarly, mass on the foot requires more energy to carry than a similar load at the body's natural centre of mass (Knapik et al., 2004).

Some loads are harder to carry than others. A 50 kg sack of sleeping bags would be more encumbering than 50 kg of ammunition. Since the sleeping bags have a large volume, much larger than the ammunition of the same weight, the centre of mass of the sack of sleeping bags is therefore a further distance from the natural body centre of mass. The greater this distance the more movement of the load there is, and the greater is the change in gait required to maintain the load (Harman et al. 2000; Knapik, 2004). So, placement of the load can be thought of as how it is being carried on the body and how far it is from the body's centre of mass. A number of studies have shown an effect on energy expenditure of altering the position of a backpack on the spine (e.g. Legg and Mahanty 1985).

The design of the load carriage equipment helps determine the load's COM. The COM of a load should be as close to the soldier's natural centre of mass as possible to minimise the load's impact on soldier agility, fatigue and injury risk.

3.6.3 Duration

The duration of carriage is just as important as total weight or volume when considering fatigue or injury. Davy and Demczuk modelled the impact of changes in load weights on total distance possible, noting that there was a limit to the distance possible by even a well-trained soldier carrying a heavy load (Davy & Demczuk, 2003). This distance was in part determined by the ground gradient, terrain type and speed of movement.

3.7 Summary

Carrying a heavy equipment burden reduces a soldier's overall performance because agility is reduced, fatigue is increased and the chance of injury is greater. Combined, these three factors can lead to reduced mission effectiveness. However, the negative consequences of carrying such heavy loads should be assessed against the benefit to the soldier and their unit of having the equipment with them when they need it.

There is a need to modify the soldier's load, but only after a proper analysis of soldier equipment need has taken place, including consideration of the loss of capability by removing items. In the future it may be possible to minimise the load a soldier carries by adopting strict 'rules' for acquisition, but in the short term trying to enforce a maximum weight is not feasible, even if it were possible to determine in the first place, since what a soldier carries is determined by a variety of disparate sources.

So, modification of the load is not restricted to simply removing an item or replacing it with a lighter alternative, it is also possible to reduce the equipment burden by improving the load's centre of mass (location on the body and total volume), and reducing the duration for which the load is carried.

There may be options for the soldier to still have the equipment there when they need it without them having to carry it all the time, or to carry it smarter. The final section of this paper will review a number of these options by examining means by which the weight, placement and duration of the burden can be reduced.

4. Near Future Solutions

4.1 Solution Framework

There has been considerable research and development effort both within Australia and internationally in the area of soldier load carriage, with solutions to excessive load offered from such diverse fields as equipment design (Bossi & Tack 2001), soldier selection (Rudzki 1989), the logistics chain (Allan & Vanderpeer 2007), and robotics (Fielding 2006). What follows is a review of many of these solutions in light of the criteria for reducing the equipment burden identified in Section 3.

If we consider the soldier burden as a combination of weight, placement and duration (see Section 3.6) we can address the problem of excessive soldier's load by examining ways to reduce weight, optimise placement and limit duration. As Figure 7 illustrates, two solutions have been identified for each of the three components of burden. The remainder of this report will describe these solutions, and detail the manner in which they might reduce the soldier's load.

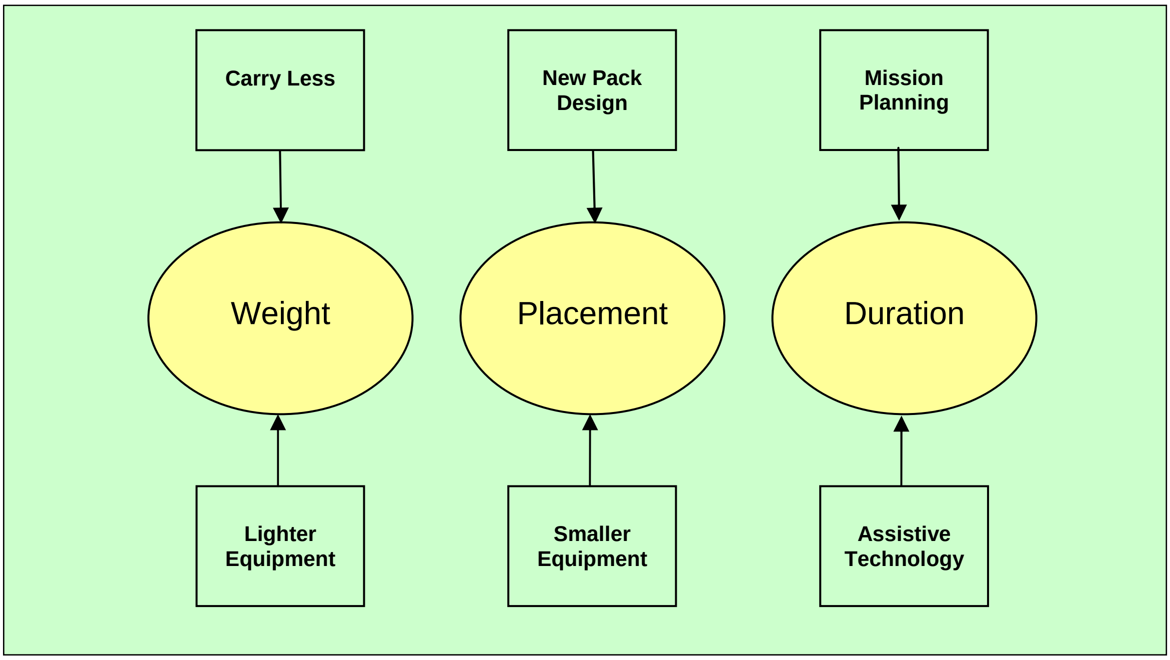

Figure 7: Three Components of the Soldier's Equipment Burden & Options to Reduce it

4.2 Reduce Weight

Almost without exception, reducing the weight of the total equipment load a soldier is required to carry will reduce the overall burden to the soldier. This is a simple strategy that has been considered by all those interviewed in the development of this report. There are two ways the total weight can be reduced; by removing equipment from the soldier, or by making the equipment he carries lighter.

4.2.1 Carry Less

Typically the three heaviest items in the load are water, rations and ammunition. Obviously nothing can be done to reduce the weight of water, however frequent re-supplies would mean less water has to be carried. At the moment soldiers typically carry 10 kg (10litres) of water. Carrying more can require the soldier to expend more energy, which causes them to heat up and dehydrate, which requires them to drink more water (Paulson 2006). If the soldier carried less than 10 litres then they would still need to be able to obtain the remaining water from another source. An option which exists at the moment is to filter and purify needed water from the environment. The problem of this solution is that the soldier must be able to know for certain he can obtain the water in order to plan. Reliance on environmental water can also put the soldier at a tactical disadvantage, since an enemy can control or sabotage a water supply. Retrieving and cleaning water from the environment also takes time, which may not be an option.

Considerable work has been carried out at DSTO and elsewhere to produce lightweight yet edible and nutritious rations for soldiers (see Forbes-Ewen 2009). The current combat ration pack weighs 1.8 kilograms. The lighter patrol ration pack weighs 1.1 kg but requires the soldier to carry water in order to hydrate the food. It may not be possible to reduce the weight much more without compromising compliance in eating the rations and providing the nutrients required.

As mentioned previously, general Regimental SOP load lists are typically treated as a requirement. They contain almost everything a soldier could need for any role they are trained. However the reality is that soldiers may not perform all their roles in a single mission, and so some of the equipment may be carried and not used. If soldiers pack only for the roles they know they will perform then there will be less 'dead weight' in their packs. What is required therefore are multiple SOP load lists based on specific roles, plus a willingness to accept the risk of insufficient equipment if an unexpected circumstance arises.

Removing items from the soldier's pack means it is not available when needed. As such, any attempt to remove items from the regimental SOP should begin with an analysis of the soldier's equipment need at different times and during different mission types.

- So, of the equipment carried, how often is each item used?
- Are there certain mission types when equipment is carried but rarely if never used?
- Are there times when equipment is carried and used once, which could instead be brought forward as needed?
- Is there equipment that all section members carry that could be reclassified as a section asset, and shared?
- Is it possible that specialised equipment be reserved for specific missions?
- Could soldiers carry less ammunition without significantly reducing their lethality?

- If we look at the burden as a section problem instead of just one man then can we reduce doubling up?
- For infrequently used equipment, how much notice do you have before you must use this equipment?
- If there is sufficient notice that an item is needed is it possible that a modified logistics chain can bring this equipment to the user as needed?

Obviously these are drastic changes that require modification to the nature of missions (see Section 4.4.1.) and/or logistics supply mechanism (see Allen & Vanderpeer, 2007).

4.2.2 Lighter Equipment Alternatives

One soldier interviewed during the Soldier Equipment Survey said "reduce the grams, and the kilos will take care of themselves". When new light-weight alternatives of in-service equipment are offered as a means to reduce the soldier's load, they often only offer a small reduction in weight and/or volume. As such it is easy to dismiss such alternatives since the difference they make to the over-all soldier's load is small. However, since that one magic solution which will take 20 kg from the soldier's load is a long way off, concentrating on many of these small reductions makes sense, as together, they can add up to provide a significant reduction.

The exact figure varies according to the type of load carriage equipment, but the pack and webbing together often weighs about 6 kg, which is 10% of the total equipment weight during marching order. Changing the materials used to make the LCE, including a light-weight frame and lighter material, may see a reduction in weight. Of course this may result in a reduction in durability also, but there is a need to determine the cost/benefit of supplying new LCE more frequently if it means a reduction in carried weight. There may also be a future benefit of utilising smart designs such as multi-use items. For example a pack frame that becomes a stretcher, or a pack that becomes a sleeping bag.

Some work has taken place on the issue of ceaseless rounds or plastic-cased rounds. The United States Army Armament Research, Development and Engineering Center (ARDEC), headquartered at the Picatinny Arsenal in New Jersey, reporting up to a 51% drop in weight with the ceaseless round compared to equivalent brass-cased 5.56 mm rounds (Spiegel & Shipley 2006). There are two main concerns with these rounds. Firstly there is often an increase in residue left within the rifle after the round is fired, causing a build-up of particles in the chamber, which can impact the workings of the firing mechanism. As anyone who has touched an expended brass round will attest, the brass case is always hot when ejected from the rifle, demonstrating that a lot of the heat generated from the primer and powder detonation is removed from the weapon by the case when fired. A ceaseless round or a plastic-cased round will not offer the same heat extraction properties, meaning the rifle will itself heat up at a greater rate than with cased rounds potentially producing *cook-offs*[6]. So clean rounds and an alternative heat dispersion system would be required to enable the use of light ceaseless rounds.

[6] A cook-off is where the round discharge is caused by the high heat in the round chamber and not the firing pin. This is an unintended discharge and has the potential to be very dangerous.

4.3 Placement Optimisation

There are operational requirements behind the decision to use certain webbing types, but there may also be detriments, especially with respect to the battlebra-style webbing. Only 11% of those surveyed in 2006 wore battlebras, but there is anecdotal evidence that this number may be steadily rising, as the battlebra gains popularity amongst infantrymen. The development of any webbing should include input from the users, ergonomists and designers. The protrusion of the pouches from the chest webbing (exacerbated when wearing a ballistic plate behind it) is likely to impede arm movements, such as raising the weapon to obtain a sight picture. The ability to 'get on your guts' may also be harder with a battlebra since your profile is raised off the ground due to the pouches and ballistic armour.

There is no one best pack and webbing combination for all roles. As mentioned in Part One, the best position of the load is high on the body when the soldier is moving on flat ground, but a low to middle load configuration is best when the soldier is on uneven terrain (Knapik et al. 2004). Milanese and colleagues (2000) noted that an ALICE framed pack coupled with hip webbing impacted the soldier the least when stationary but an internal framed pack with chest webbing impacted the soldier the least when he was performing dynamic activities. Similarly Coombes and Kingswell (2005) noted that chest webbing is more energy efficient during running than hip webbing. So, if there are to be multiple LCE per soldier then they should be divided according to the role he is performing. There are some anecdotal reports from the MEAO that this is already taking place.

4.3.1 Miniaturisation of equipment to reduce bulk

Reducing the volume of different items can reduce the overall bulk of the load. The benefit is that the load can be packed smaller and hence closer to the spine and the body's natural centre of mass. The sleeping bag is an example of an item that has been made smaller. The issued sleeping bag at the time of the survey weighed 3 kg. COTS bags, such as the Merlin Softie series are not only about one quarter the volume, they weigh nearly half of the issued sleeping bag:

- Softie3 – 0.75 kg
- Softie6 – 1.1 kg
- Softie9 – 1.4 kg

One potential negative of reducing equipment volume is that some soldiers will just use the new space made available to carry other items. This will likely have the effect of actually increasing the total weight. A new item half the size of its replacement is not necessarily half its weight.

4.3.2 New 'Ergo' Packs

When changes to load carriage equipment are carried out in an ad hoc manner incompatibilities between components can result (Sveilis 1998). There is a need to improve the ergonomics of the packs so that when full the pack centre of mass is as close as possible to the soldier's natural centre of mass. Currently, due to necessity (see Section 2.6), most of the heaviest items are placed on the outside of the pack, in the pouches. This means the current pack centre of mass is removed from the body centre of mass. However, if a pack could be designed that allowed the soldier to access the inside as quickly as accessing an outside pouch, then soldiers could place the heavier items at the 'ergonomically preferred' location, closer to the bottom/back of the pack.

Figure 8: Soldier on patrol with black day pack

The ALICE field pack issued in 2007 was 106 litres in volume. The survey reviewed at the beginning of this report noted that mounted and motorised soldiers preferred a smaller 'Sniper pack' since space in the APCs and Bushmaster was limited. The Sniper pack is typically 85 litres with an internal frame. A day pack is often used for day patrols and is typically 30-45 litres (Fig. 8). This compares to:

- 1994 Field Pack was 67 litres in volume
- 1988 Field Pack was 50 litres in volume
- 1969 Field Pack was 32 litres in volume

As such the typical day pack today is as large as the 1969 field pack. If soldiers must wear such great loads it is essential that any new pack must have a pack-belt to help redistribute the load between the hips and shoulders, improving comfort and reducing the chance of injury. The belt must be designed to integrate with the soldier's webbing and to be removed as quickly as possible.

Figure 9 shows a medics pack in closed, flap open and in fully open configurations. The volume of a medics pack is insufficient for the Infantryman but the design of a medics pack is to allow the medic access any part of the pack quickly. The standard infantry pack has one opening at the top, which means the items at the bottom are hard to access.

Figure 9: [left] Medic pack; [middle] with front open; [right] & with inside accessable

Two packs presented at Figures 10 and 11 further illustrate the concept of accessing the centre of the pack quickly and easily[7]. The first 'fold-out' pack is in effect made of pouches strung together. When bound up (Fig. 10a) the pack maintains a shape similar to contemporary packs, but when unravelled (Fig. 10b) each pouch can be accessed as quickly as any other.

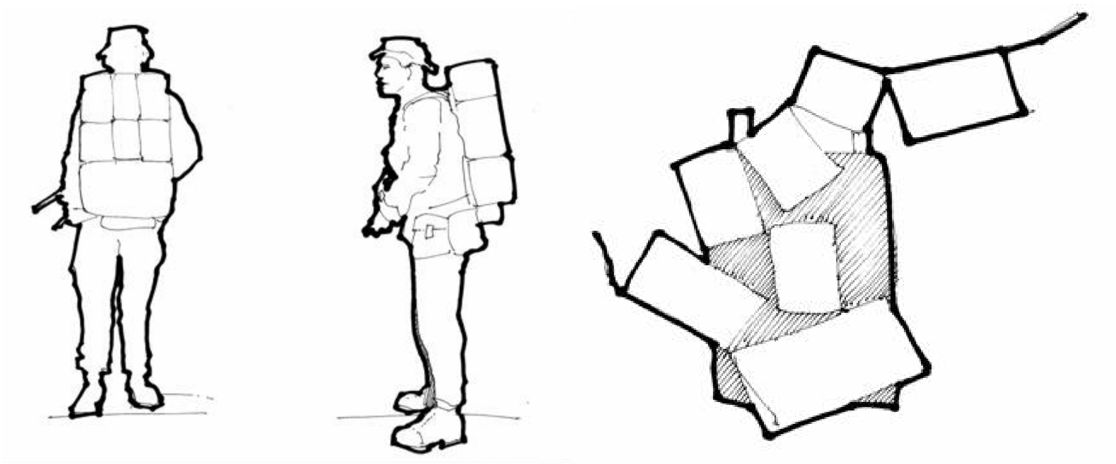

Figure 10: [left] Rear and side illustration of 'fold-out' packs [right] Detail of pack when opened

The second concept pack, called the 'Cocoon' pack (Fig. 11) consists of multiple horizontal layers, each separated from the next to allow greater movement of the overall load when the wearer is walking. The access to each layer is from the back, which means the soldier does not need to burrow through the top of the pack to obtain items at the bottom. Heavy items (water, rations) can therefore be accessed as easily at the bottom layer as at the top.

[7] The designs and drawings are by Land Operations Division, DSTO and only exist as illustrations. The intention of including them here is to put across the idea only and no effort is being made to make these packs.

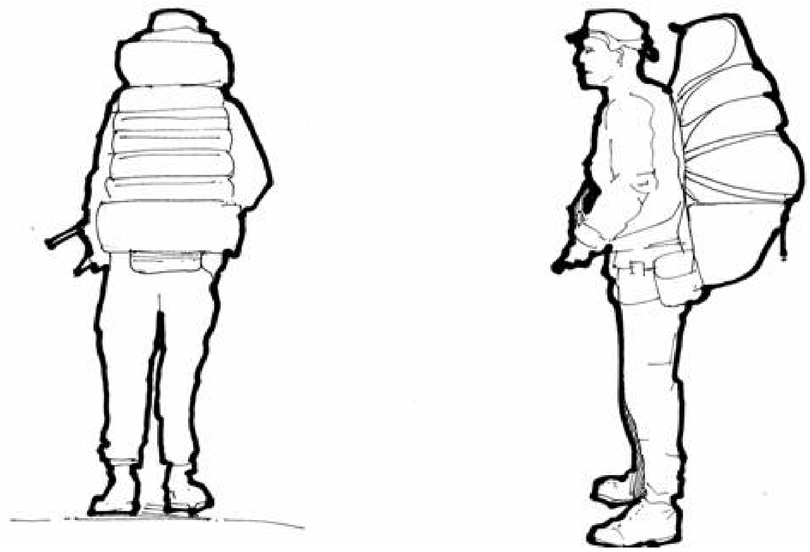

Figure 11: [left] Back and [right] side illustration of the 'Cocoon' concept pack.

4.4 Limiting Duration

4.4.1 Mission Planning

The Australian Infantryman is a generalist. He is trained and equipped to deal with a large variety of situations. When dismounted he can be independent for three days, highly mobile and difficult to detect. All these capabilities come at the cost of agility, fatigue, risk of injury, and a drop in overall performance because he must carry a large equipment set with him. In order to help solve the problem of soldier load carriage there is a need to modify infantry capability. This is not to say this capability is completely lost, but it means that more mission selection and planning is needed.

More specificity to missions may lead to shorter duration missions. Reducing the length of the mission means less water and rations need be carried. More frequent re-supply would also mean less must be carried. One option would be to push the supplies forward and not wait for a request. Pack for that mission, not every eventuality (Allen and Vanderpeer 2007).

4.4.2 Assistive Technologies

The Infantryman, with such a large equipment burden, is in effect disabled compared to his normal functioning. His agility, speed and maximum duration of travel are all reduced when carrying a heavy load. This being the case it is possible there are solutions from the field of Assistive Technologies for Locomotion that may be of benefit to the soldier.

Assistive technologies are devices that aid people to become more mobile. An obvious example is the walking cane; a simple aid to mobility that is also used by hikers (called 'hiking poles'). DSTO commissioned a report on Assistive Technologies for Load Carriage

(Milanese, 2006) which reviewed many forms of locomotor assistive technologies and examined their potential use for the dismounted soldier.

Generally assistive technologies can be broken down into two groups; those that help the soldier carry the load himself (e.g. the hiking pole) and those that carry the load for the soldier (e.g. wheelbarrow).

The 2006 review summarised that powered solutions to aid the soldier carry their own load were too complicated, required high maintenance and had high power requirements. Such devices include exoskeletons, as being explored by DARPA-funded research (Fig. 12-a) and are likely at least 20 years away (Fielding, 2006). Besides powered exoskeletons, powered exotendons have also been examined (Fig. 12-b); normally leg braces that aid the leg in bending and flexing using pneumatics. Unpowered exoskeletons such as the *Powerwalker*™ (Fig. 12-c) were also reviewed in the 2006 Milanese report but found to be too impractical. The only technology that may, with effort, be of benefit to the soldier are unpowered exotendons. Such a device returns some of the energy used when walking with a pack, back into the next step. This concept exists in nature; notably the horse hind leg tendon (Fig. 12-d).

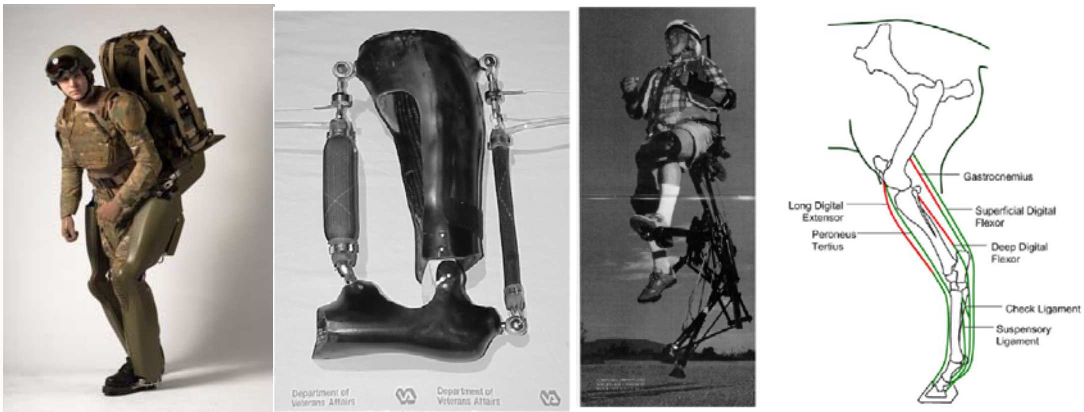

Figure 12: [a]Powered Exoskeleton, [b] Powered Exotendon, [c] Unpowered Exoskeleton & [d] Horse Tendon

Another device that requires no energy, but absorbs it for re-use is the Generator Backpack, in development at the University of Pennsylvania (Fig. 13). The pack has two aims; to reduce the energy required to carry the pack load by increasing the efficiency of the pack frame design (reducing the effect of inertia), and using the natural movement of the pack to produce energy which can recharge batteries as the soldier walks.

Figure 13: Generator Backpack. From 'Science' (vol 309, p 1726)

Other examples of devices that help the soldier carry their load include the *Segway*™, used by the South Korean bomb disposal teams to transport the heavily burdened bomb disposal experts (Figure 14).

Figure 14: The Segway.

Figure 15: Hiking Poles are good for hill ascent

Some soldiers and officers report using hiking poles also. They are of particular benefit in supporting the upper body weight when ascending slopes (Fig. 15). There is some evidence that hiking poles do not so much reduce the overall energy required, but redirect the effort to muscles in the arms that are otherwise not seeing much use.

The MULE (Multifunction Utility/Logistics Equipment vehicle) is a term frequently used to describe an unattended ground vehicle (UGV) that carries much of the soldier's equipment. DSTO has developed a Multi-role Autonomous Land Experimental Robot

(MAULER), which is a modified quad-bike capable of carrying 250 kg of kit on its flat top (Fig. 16). The MAULER is remote controlled and is a platform to research the concept of UGV.

Figure 16: The MULE[8] (left) & the DSTO MAULER (right) carrying 250 kg over sand.

Robotic devices have been used for surveillance, munitions delivery and bomb disposal but they could also be used for load carriage, within the Combat Service and Support Basis of Service (Fielding, 2006). However, they are currently dumb devices and are not expected to work with a large amount of autonomy for many years. Such devices would, at best, be treated as trained dogs, with a handler who leads them to perform a specific task.

4.5 Summary

Careful consideration is needed to determine if it is possible for a soldier to carry less and maintain the same capability he has currently. If it is not possible to remove equipment without reducing capability there needs to be consideration of what is an acceptable compromise between capability loss and performance improvement from a reduced equipment burden.

There is a need to adopt a philosophy in the acquisition cycle on reducing equipment weight by at least a few grams. As one soldier said, “reduce the grams, and the kilos will take care of themselves”. Reducing volume is as important as reducing weight. Reducing the weight of the LCE and ammunition needs considerable engineering effort.

The location of equipment on the soldier is often as important as its total weight. To that end the LCE needs to be designed to best blend operational needs with ergonomic considerations. A pack that allows soldiers to quickly access the middle contents would allow heavy items to be packed close to the soldier’s natural COM.

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[8] *(http://www.globalsecurity.org/military/systems/ground/fcs-mule.htm)*

The field of assistive technologies allows the possibility of a soldier having with them all the equipment they need when they need it without the need to have them carry it, or at least shorten the duration of carriage.

5. Conclusions

As this report has documented, the soldier equipment burden is a long-standing problem with real consequences to both the individual soldier and their combat unit. The causes of excessive load are numerous but reasonably well understood. The optimal solution to this problem is in fact likely to be many small solutions which may be identified by considering the equipment burden issue as a combination of weight, load placement and carriage duration. Small solutions taken together will reduce the burden being placed on our close combatants. Below are the key findings documented in this report:

PART 1
- The Soldier Equipment Survey demonstrated that soldiers were definitely experiencing problems of fatigue and injury with their load carriage equipment.
- Soldiers pack for utility first, and consider the ergonomics of their load second.
- Viable options for developing optimal load carriage systems must include input from the users, as well as ergonomists, designers and materials experts.

PART 2
- The significant consequences to soldiers of a heavy equipment load are poor agility, high fatigue, risk of injury and, consequently, a degradation of their performance.
- What constitutes as 'too heavy' depends on how much risk of injury and degradation in performance we are willing to accept of our soldiers.
- There is a balance to be found between the burden the equipment imposes on the soldier against the benefit that same equipment provides him on the battlefield.
- There is a need to refine the methods used to select equipment to include weight, volume and integration with existing equipment.
- What is necessary is a pervasive strategy of load reduction in all acquisition projects of relevance to the soldier.
- Be prepared to sacrifice infantry capability to solve the problem of load carriage.

PART 3
- The soldier equipment burden is not just about weight, but also equipment volume, balance and the general distribution of the load also.
- The length of time the burden is carried has a big impact on soldier performance fatigue.
- Many small changes can make a big difference: "reduce the grams, and the kilos will take care of themselves"
- Reducing load may require removing equipment, or make successfully making it smaller and lighter
- *Pack smart and smart packs*: new pack designs, coupled with new packing methods may help reduce the burden on the soldier.
- New technologies may - in the future - help the soldier.

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Appendix A: Soldier Equipment Survey Questionnaire

INTERVIEW GUIDE

INTENT: Survey the load that soldiers are carrying

1. Find out what non-standard SOP equipment is being carried
2. Determine what extra equipment is being carried
3. Examine how they are carrying it (load distribution)
4. Seek advice on how to reduce the load
5. Relate load carriage type to operational need

Intro for soldiers:

The aim of our research is:

- Reduce the weight of the load you carry
- Find an easier way for you to carry that load

To do this we need to understand what you are carrying, why you carry it and how you carry it. In general we want advice from you on how to achieve our aims.

Soldier ID# : _______________

Interviewer	: _______________	Date	: _______________
Unit/Sub-Unit	: _______________	Soldier initials	: _________
Soldier Rank	: _______________	Position	: ______________
Years in service	: _______________		

Height	: _______________	Weight:	_______________

Pack

Issued: ☐YES ↓ ☐NO ↓

Brand name : ______________________________

Frame type : ______________________________

Customised : ______________________________

Empty weight : ______________________________

Record number of pockets of each size in each location

	Small Pocket (F88)	Med Pocket (F89)	Large (camelback)
Left Side			
Right Side			
Low Back			
High Back			

Belt present / used?

Webbing

Issued: ☐YES ↓ ☐NO ↓

Brand name : ______________________________

Frame type : ______________________________

Customised : ______________________________

Empty weight : ______________________________

Record number of pockets of each size in each location

	Small Pocket (F88)	Med Pocket (F89)	Large (camelback)
Left Side			
Right Side			
Low Front			
High Front			

Pack and Webbing

Experience discomfort / injuries / pressure points / heat rash after being on CFA?

____

____

____

____

____

Experience discomfort / injuries / pressure points / heat rash after being on a field ex?

____

____

____

____

____

Ever wear ballistic armour with pack? :______________________________

How do you store body armour? : ______________________________

What job is this pack set up for? : ______________________________

<u>Content of Pack & Webbing</u>

How much water do you carry? ______________ Where? ______________

How much ammo do you carry? ______________ Where? ______________

How much rations do you carry? ______________ Where? ______________

Check pack and webbing content against SOP list

Anything on this list you are not carrying? ☐YES ☐NO → How come?

(interested in weight, volume and utility issues mainly)

____

____

____

Anything on this list is non-issue version? ☐YES ☐NO → How come?

(record brand, check it **does** to the same thing, weigh item, comment on ruggedness, etc.)

____

____

____

How do you pack your equipment?

(draw location of major components)

Why pack it this way?

____

____

____

GENERAL QUESTIONS

Alternative load carriage systems

Experience discomfort when wearing pack and webbing?

Ever wear pack and ballistic armour?

What do you think of the size of your pack? Too Small OK Too Large

What features for load carriage do you need?

Do you use a thigh holster for anything?

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19. ABSTRACT
The equipment load carried by the Australian Infantryman is so bulky and heavy that it presents a significant burden and impairment to his performance. The report aims to characterise this problem, to assess its impact, and provide recommendations from a range of disciplines. A survey of soldier equipment found it is set up and packed for ease of use, not ergonomic considerations. The load produces discomfort and injury, and reduces soldier and unit agility. All these findings are supported by a review of published literature. The report contains a description of the issues contributing to excessive soldier load, provides project management strategies and the change in the nature of operations, and ends with descriptions of six groups of solutions arrived at from examining the factors that make up the 'soldier equipment burden': load weight, equipment placement, and carriage duration.